Defining biodiversity gaps for North West Shelf marine invertebrates

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Abstract

After almost six decades of fieldwork on the North West Shelf (NWS), contemporary partnered expeditions have begun to discover and document the diverse marine biota of this area. Recent historical syntheses from the Western Australian Museum's Kimberley Project indicate over 5500 species occur in an area that includes much of the northern NWS. This compendium of biodiversity provides a new and important baseline of marine knowledge for the region. However, when considered with other NWS studies, several long-standing research gaps are evident, particularly for marine invertebrate taxa. Here we highlight and discuss these gaps in knowledge that can be grouped into five major categories: geographic, faunal, ecological, methodological and engagement. By directing future research towards these gaps, we hope to build a more complete dataset for managers tasked with protecting the many significant marine ecosystems in this extensive region.

Keywords: Barry Wilson, biodiversity, crustaceans, environmental factors, hard corals, hotspot, marine invertebrates, molluscs, North West Shelf, research gaps

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INTRODUCTION

Part of the larger Australian continental margin, the North West Shelf (NWS) is a complex and extensive marine region (Wilson 2013). The area constitutes more than half of the Western Australian coastline, and is many times larger than most European countries. It is up to two km deep and extends 2500 km along its northwest–southeast axis. Whereas other definitions of this region exist—for example, Integrated Marine and Coastal Regionalisation of Australia (IMCRA) bioregions, Thackway & Cresswell 1998)—we follow the usage of Wilson (2013), who in turn followed Fairbridge (1953). They recognized that the NWS consists of the south-western Rowley Shelf and north-eastern Sahul Shelf, the marginal terraces (Rowley and Ashmore) and the marginal plateaux (Exmouth and Scott; Figure 1; Wilson 2013, Figure 1.1). Together this area incorporates 11 IMCRA bioregions. The Kimberley, and especially the Eastern Kimberley, remains one of the least explored areas of the shelf.

The reef ecosystems of the NWS are among the most pristine in the world due to the low human population (Halpern *et al.* 2008). The region features a multitude of habitat types (Wilson *et al.* 2011) and is increasingly recognised as a cache of diversity and endemism (Richards *et al.* 2015a; ter Poorten *et al.* 2017). Western Australia is well known as a resource rich state and exploitation of these resources on land and sea have supported many industrial projects of which some predate the requirement by the Environmental Protection Agency (EPA) for Environmental Impact Assessments (EIAs). Although now routine, basic biodiversity data along the NWS was not initially collected through these means leaving a pronounced gap in our knowledge of the State's marine fauna.

The Western Australian Museum (WAM) has compiled marine invertebrate macrofaunal inventories along the NWS since the 1960s (Table 1). Although each expedition incrementally improved our understanding of the diversity and distribution of marine invertebrates in the region, it has been rare for that data, often available only in the grey literature, to be consolidated in one place. Over the last 20 years the WAM with the support of Woodside Energy and the Net Conservation Benefits (NCB) fund have focussed not only on consolidating that data but on continuing to describe the regional biodiversity and international significance of the NWS.

To date the Woodside Collection project has accumulated more than 55 000 specimens from which over 1000 new species have been discovered. Other state and federal government agencies have also recognized the importance of this region and have contributed significant investment into research undertaken as part of projects led by the Western Australian Marine Science Institution (WAMSI, https://www.wamsi.org.au), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Institute of Marine Science (AIMS). Collectively, the extent of knowledge available on habitats, biodiversity, ecological processes and their influence on marine taxa across the NWS has rapidly increased.

One of the most challenging parts of the NWS to survey has been along the Kimberley, the north-westerly shoulder of the continent where a network of 2500 islands is spread across a dynamic oceanographic setting that includes tides of up to 11 m, strong currents and turbid water (Wilson *et al.* 2011). In recognition of

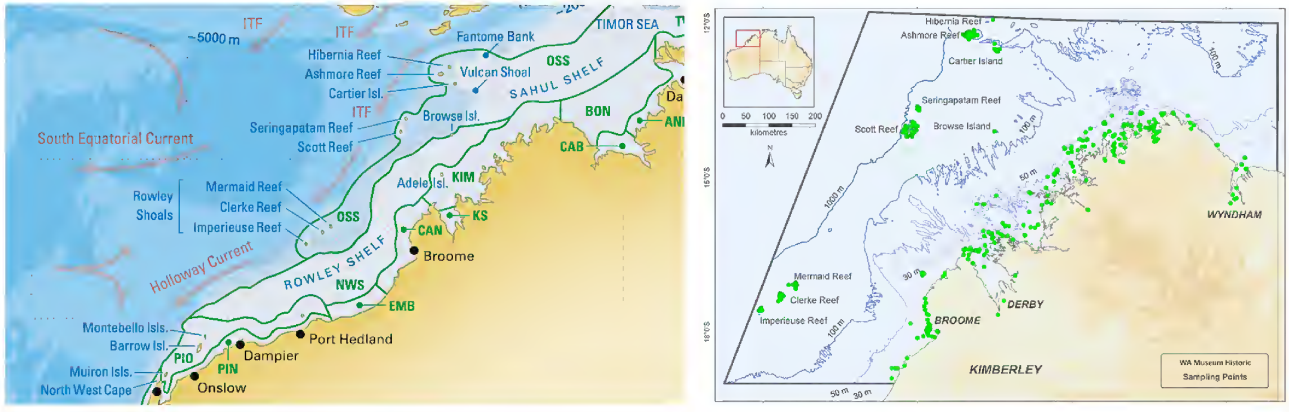

Figure 1. Left. The North West Shelf with prevailing currents and IMCRA bioregions (after ter Poorten *et al.* 2017). Right. Map of the Kimberley Project Area with Westen Australian Museum historic sampling points in green (after Sampey *et al.* 2014).

the biogeographic importance of this region, in 2009 the WAM, in partnership with Woodside Energy and collaborating institutions (Australian Museum, WA Herbarium, Queensland Museum) embarked on an ambitious project to firstly summarize all historical biodiversity records from the Kimberley (Jones *et al.* 2014–2017) and secondly, to undertake new contemporary surveys (2009–2014). Here we briefly review the combined WAM Kimberley historical dataset for eight marine invertebrate groups (hard corals, soft corals, sponges, molluscs, crustaceans, echinoderms, polychaetes and other marine invertebrates), and highlight pervasive taxonomic research gaps and emerging patterns to provide a framework for future marine biodiversity research in the region.

Marine Invertebrate Biodiversity in the Kimberley (1880s–2009)

The Kimberley Historical project assimilated verified records (excluding poorly identified material) from voucher specimens lodged in Australian natural science collections from Cape Jaubert (south of Broome) to the WA/Northern Territory border and westward to the continental shelf atolls (specifically Hibernia Reef to Imperieuse Reef; Sampey *et al.* 2014). This compendium incorporated collections from 217 locations and details over 20 000 records from shallow waters (Jones *et al.* 2014–2017; Table 2 and Figure 2).

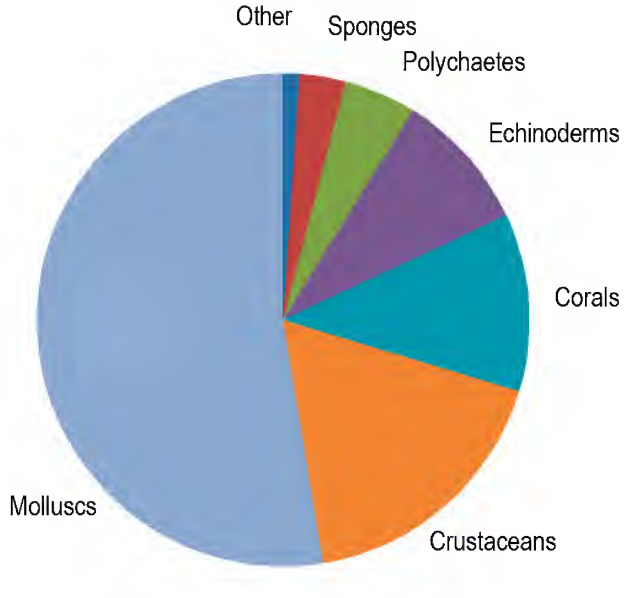

Figure 2. Visual breakdown of shallow water marine invertebrate records from the Kimberley Project Area (corals refer to soft and hard corals).

PERVASIVE GAPS

One of the most obvious trends among historical Kimberley publications is the mention of gaps by different faunal experts and the similarity of these gaps, irrespective of group. By consolidating the data collected across the eight marine invertebrate groups, we identified data gaps that are summarized under five major categories: geographic, faunal, ecological, methodological and engagement. Here we summarize these knowledge gaps and highlight emerging areas in need of further research.

Geographic Gaps

Despite ongoing work by numerous agencies, our knowledge of biodiversity and its distribution across the NWS is incomplete. We anticipate additional surveying of this region will continue to increase the number of species recorded. The regularity in discovery of new species from the region suggests that our knowledge of diversity is not saturated across taxonomic groups. For example, some of the newly described species from the NWS include bivalves (*Acrosterigma extremattenuatum* ter Poorten & Kirkendale 2017, *Ctenocardia pilbaraensis* ter Poorten & Kirkendale 2017); a nudibranch (*Moridilla fifo* Carmona & Wilson 2018); a spider crab (*Paranaxia keesingi* Hosie & Hara 2016); box jellyfish (*Malo bella* Gershwin 2014 and *Keesingia gigas* Gershwin 2014); and an octocoral, *Heliopora hiberniana* (Richards *et al.* 2018b). Many more new species are currently being described by scientists L. Kirkendale, A. Hosie, Z. Richards and J. Fromont and others at WAM.

Generally, the eastern Kimberley has been less well surveyed compared to the western areas. The 2013 survey of the King George River was the only recent

Table 1
Contemporary marine invertebrate biodiversity surveys on the North West Shelf (most recent first) resulting in significant collections (>100 WAM records). AIMS, Australian Institute of Marine Science; CSIRO, Commonwealth Scientific and Industrial Research Organisation; WAM, Western Australian Museum; CReefs, Coral Reefs survey, aspect of Census of Marine Life; ARMS, Autonomous Reef Monitoring System.

Project	Date(s)	Locality	Depth	Methods	Outcome
WAMSI 1.1.1 & WAMSI 1.1.3 Kimberley (WAM, CSIRO, AIMS)	2015–2020	Kimberley	0 m & 30–40 m	trawl, some intertidal, genetic sampling conducted	Collections of marine fauna across groups (e.g. Berry *et al.* 2017a, b)
Conservation Systematics of Pilbara fauna (WAM)	2014–2019	Ningaloo to Broome	0–15 m	hand collecting, intertidal and scuba, small hand held dredge, genetic sampling conducted	collections of marine fauna across groups suitable for genetic study, ongoing
Investigator "North West Shelf"	2017	Offshore Barrow Island	30–40 m	trawl, genetic sampling conducted	Collections of marine fauna across groups, ongoing
NCB Pilbara Expeditions	2014–2017	Montebello Islands, Exmouth Gulf, Dampier Archipelago	0–30 m	hand collecting and scuba, genetic sampling conducted	Collections of marine fauna across groups, ongoing
WAM–NCB Bonaparte Expedition	2016	Coral reefs in the Bonaparte Archipelago	Intertidal and subtidal > 15 m	hand collecting and scuba, genetic sampling conducted	Collections of marine fauna across groups, bleaching assessment (Richards *et al.* 2018a)
Pilbara Marine Conservation Partnership (CSIRO, WAM et al.)	2013–2017	Ningaloo to Dampier	10–50 m	trawl, dredge, genetic sampling conducted	collections of marine fauna across groups (e.g. Pitcher *et al.* 2016)
Royal Netherlands Institute for Sea Research Migratory shorebird study	from 2000, with return in 2017	mudflats of Roebuck Bay and Eighty mile Beach	intertidal	hand collecting to asses marine invertebrate taxa targeted by migratory shorebirds	coastal invertebrate fauna (published literature summarized in Wilson 2014)
Woodside Collection project (Kimberley)	2009–2014	Kimberley, Ashmore, Rowley Shoals	0–15 m	hand collecting, intertidal and scuba, small hand held dredge, genetic sampling conducted	collections of marine fauna across groups focused on coral reef habitats (Jones *et al.* 2014–2017)
King George River project (WAM–CSIRO partnership)	2013	Far north-eastern Kimberley	0–73 m	limited snorkelling, intertidal walks, epibenthic sled (small and large), traps, genetic sampling conducted	collections of marine fauna across groups across range of habitats (Keesing 2014)
INPEX Browse Survey	2006–2007	Bonaparte Archipelago	0–20 m	hand, scuba	collections of marine fauna across groups (published literature summarized in Wilson 2014; see also Richards *et al.* 2015)
Ningaloo CREEFs (AIMS, WAM, many others)	2008–2010	Ningaloo Reef	0–30 m	ARMS, scuba, etc, genetic sampling conducted	crabs and other crustaceans, invertebrate marine animals, shrimp, barnacles, worms, parasites, algae, soft corals and zoanthids
Woodside Collection Project (offshore atolls)	2006	Rowley Shoals, Scott and Seringapatam Reefs	0–30 m	scuba	collections of marine fauna across groups (published literature summarized in Wilson 2014)

Project	Date(s)	Locality	Depth	Methods	Outcome
R.V. Southern Surveyor "Voyage of Discovery" Project	2005–2007	Dampier to Ashmore reef	100–1000 m	trawl, dredge, some genetic sampling conducted	McEnnulty *et al*. (2011)
Woodside Collection Project (Dampier)	1999–2002	Dampier Archipelago	0–45 m	scuba, dredging	collections of marine fauna across groups (published literature summarized in Wilson 2014)
Canning Bioregion survey	1997	Beagle Bay	10 m	hand, scuba	for molluscs, sponges in 'garden bottom' (published literature summarized in Wilson 2014)
CRIMP Port Hedland Survey	1998	Port Hedland	0–10 m	hand, scuba, dredge	Collections not full identified, mostly deposited at WAM
WAM Central Kimberley Coast Survey 1996	1996	Kimberley	0–30 m	hand, scuba, dredge	unpublished reports (summarized in Wilson 2014)
WAM Eastern Kimberley Survey 1995	1995	Kimberley	0–30 m	hand, scuba, dredge	unpublished reports (summarized in Wilson 2014)
WAM Southern Kimberley Islands Survey 1994	1994	Kimberley	0–30 m	hand, scuba, dredge	unpublished reports (summarized in Wilson *et al*. 2014)
WAM Kimberley Islands & Reefs Survey 1991	1991	Kimberley	0–30 m	hand, scuba, dredge	plant, invertebrate, fish collections (published literature summarized in Wilson *et al*. 2014)
WAM Kimberley Islands Survey 1988	1988	Kimberley	0–30 m	hand, scuba, dredge	collections of marine fauna across groups (published literature summarized in Wilson 2014)
Ashmore and Hibernia Reefs & Cartier Island surveys	1988	Ashmore and Hibernia Reefs & Cartier Island	0–30 m	hand, scuba	collections of marine fauna across groups (published literature summarized in Wilson 2014)
Kimberley Mollusc Surveys	Oct–Nov. 1976, 1988	Institut Islands, Cape Voltaire and Admiralty Gulf as well as other islands in Kimberley bioregion	0–30 m	hand, scuba	Mollusc lists (published literature summarized in Wilson 2014)
Crown of Thorns Expedition	1972–1974	Dampier Archipelago	0–30 m	hand, scuba, dredge	Incidental collecting, main aim was to survey crown of thorn seastar numbers
CSIRO scampi surveys	1984	Broome and Augustus Island	200–600 m	engel trawls	benthic invertebrates

Project	Date(s)	Locality	Depth	Methods	Outcome
Browse Island marine ecology	2005–2008	Browse Island	0–30 m	intertidal (hand) and subtidal (scuba, video, ROV) surveys	Coral and mollusc ecological surveys (Comrie-Greig & Abdo 2014)
Rowley Shoals, Scott & Seringapatam Reef surveys	1982–1984	Rowley Shoals, Scott &, Seringapatam Reefs	0–50 m	hand, scuba	collections of marine fauna across groups (published literature summarized in Wilson 2014)
CSIRO scampi surveys	1979, 1982	Rowley Shoals	276–520 m	engel trawls	benthic invertebrates
Umitaka Maru surveys	1969	17 stations from Joseph Bonaparte Gulf to Rowley Shoals	29–260 m	dredged	molluscs deposited to WAM
Dorothea Expedition	1962	Kimberley coast	22–90 m	dredged	benthic invertebrates

study that ventured east of Cape Londonderry. This study documented 736 marine invertebrate species from a variety of habitats across 150 stations using diverse methods (Keesing 2014, Table 1). However, species accumulation curve predictions indicate the true species richness of marine invertebrates is likely to double with further sampling (Keesing 2014). Future surveys in the vicinity of Admiralty Gulf and Cape Bouganville such as the Sir Graham Moore Islands, Troughton Island, Eclipse Islands and Holothuria Banks are warranted along with the Berkeley River to Cambridge Gulf region. Furthermore, some areas in the western Kimberley are still data poor including the Lacepede islands, the entire western edge of Dampier Peninsula, King Sound and the Buccaneer Archipelago.

Robust biodiversity datasets are available for offshore atolls (see Wilson 2014 for a summary). However, invertebrate biodiversity at many of the submerged banks and shoals is largely unknown. For example, Fantome Bank and nearby Vulcan Shoals are unsurveyed and lightly surveyed, respectively (ter Poorten *et al.* 2017). Preliminary ROV work has also revealed extensive coral communities near Browse Island (Andrew Heyward, pers comm, Sept. 2017). The WAMSI 1.1.1 project has highlighted that extensive inter-reefal soft-sediment benthic communities (most specifically sponge and soft coral gardens) exist across the shallow Sahul Shelf and further surveying of habitats below 30 m is likely to reveal additional biodiversity (Table 2).

Table 2
Summary of shallow water (>20m depth) marine invertebrate biota from the Kimberley Project Area (after Sampey *et al.* 2014).

Group	Shallow water records	Excluded records (deep water/ incomplete identification)	Shallow water species
Sponges	665	236/406	342
Hard Corals	2423	69/243	338
Soft Corals	140	9/505	63
Echinoderms	2014	74/325	382
Polychaetes	1046	0/812	261
Crustaceans	3893	840/4700	882
Molluscs	11551	3347/5383	1784
Other marine invertebrates	229	7/364	121
Total	21961	4582/12 738	4173

Faunal Gaps

Organism bias is prevalent in biodiversity research and can depend on the perceived value, including commercial, of particular taxa, as well as available taxonomic expertise. This is seen at high taxonomic levels for groups such as sponges, non-scleractinian Cnidaria and Bryozoa that historically were underrepresented. Moreover, more than 80% of records in the Kimberley Historical project relate to molluscs, crustaceans and scleractinians (Figure 2). Within groups this bias is also apparent, for example, the order Decapoda represents only 31% of total crustacean species recorded from Australia, but makes up 85% of the WAM crustacean dataset (ABRS 2009; Hosie *et al.* 2015). The diverse morphology in Crustacea is such that specific orders often require experts thereby focussing resources to the exclusion of other crustacean taxa. A compounding factor is size, as it is generally more difficult to identify smaller than larger species across different taxonomic groups. This is largely a function of handling time associated with sorting, requirement of microscopy and utility of photography (Middelfart *et al.* 2016). Although, crustacean infauna (e.g. benthic copepods, ostracods) were collected during recent Kimberley biodiversity surveys, sampling was not comprehensive and there was

a lack of resources (funds, expertise) to fully curate these collections.

Similarly, preliminary investigations of micromollusc fauna indicate an astonishing diversity (Middlefart *et al*. pers. comm. Jan. 2019); however a lack of funding has constrained work to the morphospecies identification level only. Other sessile marine invertebrate taxa such as sea pens, ascidians, zooanthids, hydrozoans and anemones also require further study. In addition, little is known about the sea jellies including stingers that inhabit the region. Specimens from some of these groups housed at the WA Museum are available for examination by relevant experts. Further investment into taxonomic studies is warranted across a broad range of marine invertebrate taxa given the strong likelihood that many new species will be revealed.

Ecological Gaps

Although much of the world's seafloor habitat is soft sediment (mud, clay, sand), studies of the marine invertebrate fauna in soft sediment are notably sparse in WA, and the NWS is no exception. Eighty Mile Beach, for example, incorporates expansive sand and mudflats, recognized as a Ramsar wetland of international significance and recently gazetted as a marine park, at present better sampled by international groups (Dutch-led) rather than State or Federal agencies. Whereas the importance of coral reef habitats is undeniable, other habitats are important too, playing a role as sources of evolutionary novelty and underpinning the productivity and integrity of the wider marine ecosystem and food webs. Mangroves, for example, can be challenging to access but are well recognized as nursery habitats for many marine groups and are expected to have specialized invertebrates that await documentation. Similarly, sandflats, and particularly the marine invertebrate infauna of these systems, provide abundant food for many migratory seabirds that find refuge in the Kimberley along with other taxa of biological and cultural significance such as sawfish (Department of Fisheries 2018).

Even in well-studied taxa, such as molluscs from relatively well-examined habitats such as coral reefs, we know little about seasonal faunal shifts and nocturnal transitions (Richards *et al*. 2018a). For motile fauna, including molluscs and crustaceans, reefal biodiversity is best captured during nocturnal surveys; however, this is rarely feasible given current dive-safety restrictions.

Shallow-water habitats are better sampled than deeper ones. This is well illustrated by the Kimberley Historical project, in which only 16.5% and 9% of mollusc and crustacean WAM records, respectively, were collected from depths below 30 m. Recent projects have begun to fill some knowledge gaps. For example, Poore *et al*. (2015) collected specimens to depths of 1100 m and sampled over 1100 crustacean and 359 mollusc specimen lots respectively from 30–100 m during the recent WAMSI 1.1.1. Project. Future collaborative projects between the WAM, AIMS and Curtin University aim to address this imbalance (e.g. Schmidt Ocean Institute Expeditions planned for 2020), and are likely to reveal entirely new fauna and communities and address longstanding questions regarding the importance of submerged coastline habitats along the NWS.

Although new work is proposed, the petroleum industry has logged many more hours in WA's deep sea than have other groups. This represents a clear opportunity, given the experience and capacity of the industry, to work together to better document our deep-sea biota. As well, there is considerable data in unpublished work that is held as commercial in confidence. More use could be made of these data if unpublished reports were shared and voucher specimens were deposited with the WAM.

Methodological gaps

Describing new species and assessing phylogenetic relationships across major branches of the tree of life can be a daunting task for which genetic methods are critical (Wilson & Kirkendale 2016). The importance of genetic methods in screening diversity broadly is perhaps best highlighted by the discovery in 2013 of a new lineage of giant clam based entirely on sequence data (Huelsken *et al*. 2013). However, genetic data alone can be insufficient to make robust interpretations about phylogenetic relationships; hence an integrated approach (see Richards *et al*. 2018b for an example) utilizing all evidence is the best-practice for modern taxonomy and systematics.

Many research expeditions have begun to focus on the collection of ambient and ultra-freeze tissue specimens for genetic analysis along the NWS (Table 1). Whereas sampling specimens appropriate for future genetic analysis is routine, unfortunately little funding exists for downstream application. Moreover, the time and funds required for analysis, storage and publication of genetic data is usually minimal and more funding needs to be made available for post-collection analyses in biodiversity discovery projects. One major collections-based project across faunal groups is underway at the WAM via the Net Conservation Benefits project. The goal of this long-term project has been to build phylogenetic trees to better understand systematic relationships among sensitive taxa in the greater Pilbara area (from Shark Bay in the south to the southern Kimberley in the north, representing a significant part of the NWS). Whereas this project is an important start, many marine invertebrate taxa are beyond its scope indicating much more work remains to be done.

Emerging technologies such as environmental DNA (eDNA) also offer alternative and complementary ways to detect biodiversity. While eDNA surveys have the potential to identify biodiversity hotspots that could be worthy of closer scrutiny, the accuracy of eDNA audits relies on the availability of genetic reference material, even when analysed at the level of operational taxonomic units (OTU's).

Engagement gaps

The protocols for undertaking marine science in Western Australia have advanced considerably over the last decade. Today 'right way science' focussing on traditional owner engagement and collaboration is firmly established as the model for future research on the NWS, and protocols are available to guide that process (Austin *et al*. 2017, see also: https://www.klc.org.au/research-facilitation). Further work is needed to integrate traditional ecological knowledge and management practices into Kimberley marine conservation and

Figure 3. Compendium of select marine invertebrate fauna from the North West Shelf. A. *Lobophyllia hemprichi* at Ashmore Reef, B. Intertidal *Acropora* assemblage in the Kimberley, C. The ectoparasitic gastropod *Thyca crystallina* on blue seastar *Linckia laevigata* from Imperieuse Reef, Rowley Shoals. Scale = 5 mm, D. *Trapezia cymodoce* in *Stylophora pistillata* at the Montebello Islands. Scale = 10 mm, E. An interstitial cumacean from Montgomery Reef. Scale = 1 mm, F. *Uroptychus* sp. nov. from Rob Roy Reef. Scale = 10 mm, G. A benthic ostracod from Montgomery Reef. Scale = 1 mm, H. A diverse intertidal coral community at Patricia Island, Bonaparte Archipelago, Kimberley, I. *Hypselodoris* nudibranch from Imperieuse Reef, Rowley Shoals. Scale = 4 mm, J. *Daira perlata* from the Kimberley. Scale = 5 mm, K. *Pocillopora grandis* at Browse Island, L. *Moseleya latistellata* in the soft sediment at Dampier Archipelago, M. *Rochia nilotica* from Scott Reef. Scale = 30 mm, N. *Spondylus* clam from Imperieuse Reef, Rowley Shoals. Scale = 50 mm, O. *Tridacna* from Mermaid Reef, Rowley Shoals. Scale = 50 mm, P. *Paranaxia keesingi* a newly described species from NW WA. Scale = 30 mm, Q. *Agostodina munta* from the Montebello Islands. Scale = 5 mm.

management and to enhance mutually beneficial collaborations between indigenous peoples and non-indigenous partners that are focussed on research in 'saltwater country'.

Partnerships with industry also form a unique component of research facilitation in Western Australia—they will be important to continue to build and foster relationships and conduct demand-driven research (e.g. deep sea and decommissioning) to achieve multiple outcomes. Another important gap that requires renewed and ongoing investment is the ability to attract, train and retain the next generation of WA marine invertebrate taxonomists. There are five universities in the Perth area but few undergraduate programs develop student taxonomic capacity in invertebrates. Although this is certainly a worldwide trend, this is in spite of ongoing work that reveals many unsurveyed areas, likely with many species yet to be discovered, and many threats jeopardizing this diversity in WA. This is a significant gap requiring strategic focus.

SUMMARY

The issues facing marine invertebrate taxonomy in Western Australia are not endemic to the State and require a synthetic, broad-based approach for improving biodiversity research nationally. Many of these issues are highlighted in the newly released *Discovering Biodiversity: A decadal plan for taxonomy and biosystematics in Australia and New Zealand 2018–2027* (Taxonomy decadal plan working group 2018). Please also refer to https://www.taxonomyaustralia.org.au/.

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There have been several fitting tributes to the prolific career of Barry Wilson, who passed away on 12 June 2017 at the age of 82. One of the most recent has been the dedication of *Marine Biodiversity of the Kimberley 1880s–2009* by WAM given his body of research in this area. The span of work completed by Barry was as immense as his intellect; he touched on many disciplines including molluscan taxonomy, invertebrate biodiversity and biogeography and marine conservation, and many lives as a result. We are grateful for the foundation he has laid at the WAM, and in Western Australia and we dedicate this paper to him.

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